AD-A174 303 THE USE OF NEW TECHNOLOGY IN THE CONTROL OF CIVIL AIR TRAFFIC AT AIRWAY J..(U) ROYAL SIGNALS AND RADAR ESTABLISHMENT MALVERN (ENGLAND) P T HUMPHREY JUN 86 1/1

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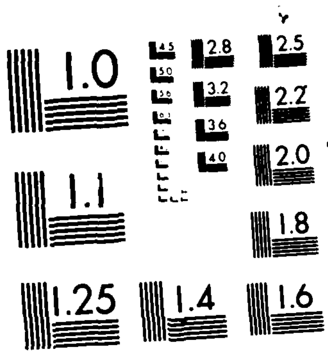

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UNLIMITED

Report No. 86007

ROYAL SIGNALS AND RADAR ESTABLISHMENT,
MALVERN

THE USE OF NEW TECHNOLOGY IN THE CONTROL OF CIVIL AIR TRAFFIC AT AIRWAY JUNCTIONS

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June 1986

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Date: ~~April~~ JUNE 1986

SUMMARY

This Report considers the methods which are used to deal with airway junctions at present and reviews how new technology could impact on this process in future.

RSRE Task: 165

CAA R&D Programme Item: 2.2.1.1

CAA Sponsor: Chief Scientist

CAA Liason Officers: RD1, DPA1, Tels C3

This Report reflects the views of the author. It is not to be regarded as a final or official statement by the UK Civil Aviation Authority.

Work done under contract to the
UK Civil Aviation Authority

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The Use of New Technology in the Control of Civil Air Traffic at Airway Junctions

1 INTRODUCTION.

An airway junction where two or more routes merge or cross is a significant influence on the capacity of the airway system and a major factor in the workload of the controller of the sector. It is the pattern of junctions which really characterises the airspace. The reason for this paper is to discuss how the implementation of some computer assistance could alleviate some situations particularly in conjunction with advanced aircraft flight management and navigation systems.

The capacity of a junction will be discussed and the methods of control which are used at present outlined. Also the practical problems which influence the handling of traffic at junctions will be highlighted. Then, the characteristics of aircraft as they will develop together with other technical ATC system developments will be reviewed. Finally, the new methods of air traffic control which may become possible will be presented.

2 THE PHYSICAL CAPACITY OF A JUNCTION.

The physical capacity of a route may be defined as:

> The number of flight levels (determined by the airspace design) X
>
> The flow rate per flight level.

If two routes cross or merge then the capacity of each route at that crossing point is controlled by that junction capacity, and it will be less than either of the routes alone. This is the physical capacity and does not include any constraint which may be imposed by the limitations of controller workload or other factors.

The airspace designer has the task of arranging the routes between the FIR entry points, exit points, the destination and originating airfields. He has constraints imposed by the agreed military areas, urban areas and the limitations imposed by environmental factors such as aircraft noise and the limits of average aircraft performance. This is besides the rules he must follow to produce route profiles which are acceptable to the controller and the air crew. The end result may be that he is driven to divide up the airspace in a way which reflects the controller workload levels, which are implied by the sectorisation which he assumes, and not by the actual airway capacity limits. With high traffic levels at crossing points the resort is to procedural methods as opposed to radar control. This means that the workload is minimised but the capacity is also reduced. One benefit from giving more computer assistance to the ATCO is that the airspace designer could have a third category of control introduced between procedural and radar control. This would have the potential to permit higher capacity and more flexibility than with procedural control but without the increased workload demanded by radar control to do the same job.

3 AIR TRAFFIC CONTROL AT JUNCTIONS.

There are three basic methods which can be used to control traffic at a junction. A mixture of them is also possible.

3.1 By Flight Level.

Each route is allocated specific flight levels on which the traffic may fly and from which traffic on other routes is excluded. This procedural separation by height is safe but dramatically cuts the junction and route capacity. For two routes with equal traffic levels, their capacity would be halved. To balance this, the workload of the controller is minimised.

However there is also an economic disbenefit from sharing flight levels because it will only be one of the routes which will have use of the level which is chosen as the economically optimum by a particular operator. This level is likely to be also in demand by other operators which can lead to considerable bunching in height. Other routes will have to make do with the less economic levels. To exacerbate this, above 29000ft the flight levels are separated by 2000ft not just 1000ft. Therefore, for example, if two upper air routes cross and the levels are shared by interleaving , then for the route which has the optimum level the next nearest level available to it will be 4000ft higher or lower. This is economically very significant. The effect is further magnified if more than two routes have to share the levels at the junction.

If the controller has the authority, he may use the levels which may have been allocated to one route to alleviate the situation on another at a junction, but this will be a tactical decision.

The reduction of the vertical separation above FL290 from 2000 ft to 1000 ft, which is under consideration, would of course provide some extra levels which would assist.

3.2 By Sequencing.

The available flight levels may be shared between the routes at a junction by sequencing the traffic using speed control to achieve the required horizontal separation. The controller will have an increased workload over the previous method but the desired flight levels will be available to both routes. The horizontal spacing which the controller will use will be determined by the closing rate of the aircraft and the attention which he can afford to devote to the task.

The problem with crossing traffic at the same flight level is caused by the uncertainties in,

(a) the aircraft velocity particularly where there may be high closing speeds;

(b) the aircraft position measurements made both by the ground radar and on board the aircraft themselves;

(c) knowledge of the wind conditions to be encountered before the junction;

(d) carrying out the requested procedures because of either equipment malfunction or human errors.

The standard procedural longitudinal separation is 10 minutes and this would normally be applied outside radar cover. It is as large as this because the controller only has position reports from the aircraft as they pass over beacons and so there is a substantial margin for error and for communication delays.

Under radar control (ie. the controller deriving the aircraft speed and position by eye from the radar screen but having no detailed upper air wind information) the procedural rules can be relaxed somewhat but there are still major uncertainties in (c) and (d). For this reason, crossing traffic at the same level under radar control demands a high controller workload because they must monitor the progress of the pair of aircraft concerned and leave enough time for intervention in an emergency. In practice, the controller within radar cover would cross the aircraft at the same level with some comfortable horizontal separation which is not too demanding, for example, perhaps about 2 minutes or 15 Nmiles.

The aim of the application of new technology would be to reduce the uncertainty in these factors listed above and so reduce the workload entailed by the control of air traffic by this means.

3.3 By Vectoring.

If he has sufficient space for manoeuvres, the controller can change the heading of one of a pair of potentially conflicting aircraft so that they will have a safe separation (see Fig.1). They may or may not be in level flight and it will be at the expense of extra track miles.

4 PRACTICAL SITUATIONS.

To give some intelligent consideration to how the methods of control at junctions may be improved, some of the practical situations which are encountered and some which may have to be faced in future will be reviewed.

4.1 Simple Junctions.

A simple junction is one where there are only two routes crossing and which is not near any other junction. The method used to control the traffic at the moment will depend on the traffic conditions at the time but could be any of those which have been outlined above.

4.2 Multiple Junctions.

Good European examples of complex multiple junctions are in Northern France and over Holland.

4.2.1 Northern France. - Over France the traffic on major routes such as from NE Europe to Spain crosses those going from UK to the Mediteranean. Over this region there also occurs the process of merging the routes which come from UK, Germany and Scandanavia to go to Spain. This poses a complex problem to the controllers.

The basis of the method used at present to deal with the conflicting demands is to organise a strict allocation of flight levels to the donor sectors which allows the traffic to flow with specified maximum rates and ensures that the controller does not normally have to resolve conflicts. The effect of the 'Flow Control' is to reduce the route capacities below the peak demand and to give to some routes very uneconomic levels but the controller has a manageable task. The complexity of the airspace and the density of traffic means that these levels are not given just in the immediate area of the junction, but become fixed for longer periods of flight.

The overall level of flow control is also determined by the capacity of the receiving sectors and airports. This system requires long term planning (to allocate the levels and the flow rates) which consequently makes short term operations inflexible.

A benefit to an area of airspace such as in Northern France of crossing traffic at fewer levels would be that more space would be left underneath for the TMA traffic.

4.2.2 Amsterdam. - The SPY-PAM region of the Amsterdam FIR has to deal with five major busy flows of traffic which intersect there together with traffic from a major airport. Fig.2 shows the en-route route structure (from Ref.1). An ETA planning system called SARP has been introduced to enable the flows to be planned and the same flight levels to be shared. A horizontal separation criterion of 10 Nmiles is used. It has been reported in Ref.1 that over a six month period, for some 500 level flying aircraft, the mean and standard deviation of the difference between the actual and estimated arrival time over some 15 minutes flying time was 13 secs and 81 secs respectively. However, 20 aircraft were observed to have a time difference greater than 180secs. The reasons given for this were,

= unreliable wind estimates,

= flight path deviations caused by pilots and controllers,

= discrepancies in the estimate of actual aircraft performance due to,

  * noncompliance with assigned air speed,

  * unrealistic assessment of aircraft performance by the SARP program,

  * errors in keying in information about aircraft type,

* aircraft type differing from the flight plan.

In summary, the operation of complex airway junctions is determined by the controller workload, the complexity of the airspace design and the capacity of the adjoining sectors. It can be helped by the use of some computer assistance, such as a basic planning aid for the controller, but already experience shows that even at this elementary level it leads to a need for more precise information about the wind, the aircraft flight path and the aircraft type and performance. It is here that the application of a further stage of technology based on an ATC data link can provide the extra assistance as the discussion in sections 6 and 7 will indicate.

4.3 Dual Track Airways.

There are some upper air dual track airways in operation in Europe along the major traffic flows (for instance, the route from UK to Austria and Scandanavia to Spain) at the moment but these could become more common in future. They are parallel, unidirectional routes separated laterally by 8 Nmiles which offer the opportunity of the economically desireable levels to more traffic. More such airways may be made possible by the increase in navigational accuracy of aircraft. However there is a significant task for the controller in monitoring such airways.

In UK airspace there are some sectors which have a method of working which is similar to dual track airways, although there are some differences. In the Clacton and the Daventry sectors which have a heavy peak load of traffic, parallel unidirectional routes are formed in the airway. In Clacton the spacing is achieved by using the Clacton and Brookmans Park beacons and the Longsands and Lambourne beacons. In the Daventry sector, the parallel routes are formed by giving the aircraft headings to fly, not by using beacons.

At the moment dual track airways are seen as routes which are joined and left only at the ends so that there are no routes which merge. To permit this merging of routes so that traffic could join and leave at any point raises some difficulties. If an aircraft wants to join from one side of the airway and some time later to leave from the other then, however it is done, both tracks will have to be crossed.

4.4 The Terminal Movements Area.

The discussion above has been of crossing traffic in level flight at the same flight level, but in the TMA much of the traffic is still climbing and descending. In present UK practice, under radar control, traffic would be crossed under these conditions with normal radar separation with the controller monitoring the situation closely. SARP does deal with the TMA but it has to derive ground speed (sometimes not very accurately) from the radar tracker and it uses more detailed information about aircraft type and company practice than is normal for ATC (Ref.1).

The alternative approach to the TMA problem is to separate the routes procedurally and so ensure that the traffic does not conflict. This is attractive in a more complex TMA than Amsterdam and typical of this method of airspace design is the New York Metroplex system and the proposed design for the future London TMA. These are attractive because they increase capacity without increasing the workload of controllers or the number of controllers. (This latter factor is not just a matter of staff numbers but of intercommunication problems). The penalty would be that for some routes the route-miles flown will be greater than at present but this must be off-set by the time-cost savings by having fewer delays at peak times.

5 THE USE OF SPEED CONTROL.

5.1 Area Of Control.

Implicit in the discussion of speed control is a designated area *of control*. The decision on how to sequence the traffic needs to be made a certain distance from the junction and this specifies the radius of the area of control. It follows from this that if a group of junctions are closer together than this distance then they must be considered as a whole when planning the traffic. Also, the distance between groups of junctions must be greater than the control distance.

The range of adjustment is the amount of variation that the controller can introduce in the position of an aircraft. It may be seen that the range of adjustment is dependant on the speed variation which is possible in the aircraft at the height at which it is flying. For instance, to achieve an increase in separation of 10 Nmiles in a specified time with an allowable speed variation of 20%, the control distance would need to be 50 Nmiles. This measure of control means that speed control must be considered as a method of long term tactical control which will need an associated redesign of the affected airspace to be effective.

5.2 The Permissible Speed Variation.

The difference between maximum and minimum true air speeds of aircraft decreases strongly with increasing height. At the normal economic altitude for a modern jet, the permitted variation of speed may be only some 10% which therefore greatly restricts the control range. The maximum and minimum speeds (Vmax and Vmin) are for an aircraft type for a particular set of conditions which are stated in the manufacturers data. (The operational values may also be modified within these limits by the operating practice of the airline concerned). This means that if the ATC sequencing system is allowed a range of speed control V'max to V'min at a particular height then

$$V_{max} > V'_{max} \text{ and } V_{min} < V'_{min}.$$

Consider first the situation when the sequencing of traffic by speed control is used by the ATC system. The speed variation which is left to the aircraft must be sufficient for it to maintain control at each end of the speed range. However, consider the situation when the ATC system not only sequences the traffic (for instance through a junction) but also seeks to use the 4-D capability of the aircraft to do so. To exercise that capability the aircraft must be left sufficient speed margin to cope with any unplanned occurances such as wind forecast errors and this will require a larger proportion of the allowable range of speed than with open loop speed control. Thus it may be seen that there is a relationship between the accuracy of the wind forecasts and the number of times that an aircraft will not be able to achieve the desired time slots because it did not have sufficient speed control.

The consequence of this is that, if speed control were to be used to sequence traffic through time slots at a junction, there could be advantage in some circumstances in bringing the highest flying aircraft down to an altitude where they would have a larger range of speed control, say from FL410 to FL330, which would be a serious matter for the airline operator. This requires a balance to be struck for an individual aircraft between the economy of flying high and the ability of the ATC system to increase system capacity and minimise overall system delays.

5.3 Design Of Multiple Junctions.

Further complication is introduced by considering more than two routes crossing at the same flight level at one point. In general if they are all to cross at the one point at the same level then the control range needs to be greater; for 'n' routes, the control range should be , in simple terms, 'n-1' times the separation distance. This is deduced by the following argument. If a time slot at the junction is allocated for an aircraft on route no.1 and then immediately after that decision was made an aircraft presents itself on route no.2. This will have to be delayed by one separation distance. However if another aircraft on route no.3 then arrives at the decision boundary it would have to be delayed by two separation distances and so on for each route which shares that junction.

Up to the present day navigation has been done by overflying beacons and this concentrates traffic at the beacons and also facilitates easy visualisation and control by the controller of the traffic pattern. Area navigation systems would enable accurate flight paths to be defined off-set from the beacons but the controller would need assistance to plan the traffic sequence through the resulting complex junction.

The results of studies in the past have shown that there is little benefit in redesigning just one junction in an area of several junctions (Ref.2). This work was done to see if their was benefit in employing height monitoring at a busy junction which could lead to a local reduction of vertical height separation limits above FL290 at that junction. The conclusion was that complex junction systems have to be treated as a whole before any significant increase in capacity can be obtained.

5.4 Closing Speed.

The closing speed of a pair of aircraft varies with the cosine of the angle of intersection of the routes at the junction. The high closing speeds which are possible contribute to the risk of crossing traffic at the same level since they leave the controller very short reaction times. In considering junctions in future, any computer assistance could employ a separation at the junction which is a function of the intersection angle and the closing speed so that the minimum time separation is a constant.

6 TECHNICAL ADVANCES.

The advances which could be used to contribute to this new ATC system arise from three technical developments, the new generation of avionics, the ATC data link and the advent of an airborne collision avoidance system (ACAS).

6.1 Aircraft Characteristics.

Although it has been well reported (Ref.3,4,5), it is worth summarising the trend that has already begun in the civil aircraft avionic and navigational equipment. It has become economically attractive to fit flight management system (FMS) and area navigation systems which permit the aircraft to fly in a much more precise fashion. The figures measured in Ref.6 were for an experimental aircraft but they should be representative. For a DME/DME/Inertial system the mean was less than 0.05 Nmiles and the standard deviation less than 0.2Nmiles. No longer need routes be specified by the requirement to overfly beacons but they can be defined with complete freedom within a pattern of DMEs. It may be expected that the route will be flown much more accurately than at present, particularly once the method of flying turns has been standardised.

The vertical flight profile also may be flown in a much more tightly defined way than previously possible and the optimum tends to be close to that of other aircraft types. With sufficient information (such as the wind forecast along the route) it may be optimised for the greatest economy and, what is more interesting from the point of view of handling traffic at junctions, the time of arrival at any point along the route may be predicted much more accurately than was possible in the past. The order of accuracy which may ordinarily be expected in commercial service will be that being demonstrated by aircraft such as the RAE Bedford 1-11 at present which is less than 10 seconds to a point in space over a flight time of 30 minutes and including a descent from cruise level (Ref.7). The reliability and economy with which this may be done will depend on the knowledge of the future wind along the intended profile.

A very significant feature of this progress in avionics is that it is not just new aircraft which are having such equipment fitted. It is proving economically worthwhile refitting old aircraft with a simpler form of FMS and accurate area navigation which can reduce operating costs and it will be one important fact which may prolong their useful lives. The consequence of this is that the proportion of the traffic with some of these new capabilities is likely to increase very quickly, not just at the rate of production of new aircraft.

An additional navigation technique which is still at the stage of feasibility studies is the use of satellites. There is an increasing pace of research into their civil use for navigation by land sea and air vehicles which will undoubtedly produce fruit for some applications. This must be coupled with the imminent introduction of the military NAVSTAR GPS with its associated civil mode of use which means that there is in prospect a system of global accurate navigation independent of ground aids.

6.2 An ATC Data Link.

The data traffic may be placed into four classes.

(i) Aircraft Parameters. It would be possible to send to the ground information at frequent intervals, or perhaps when values change by some significant amount, on a selection of aircraft parameters. These could include,

Heading/Track: To aid ground tracking.

IAS/TAS: To supplement the information from flight plans or radar tracking.

Descent Rate: To aid tracking.

Roll Angle: To aid tracking.

Turn Rate: To aid tracking

Latitude/Longitude: To aid tracking.

(ii) Aircraft Intention. It would be valuable to send to the ground information about the intention of the aircraft which is inserted into the FMS by the crew in flight planning and after take-off. Examples of this might be,

Next Waypoint.

Demanded flight level or speed or heading.

Change of mode of the FMS.

(iii) Met Data. In aircraft equipped with IN systems the instantaneous wind speed and direction are derived in the avionics and therefore may be sent to the ground along with the air temperature. Also on the uplink may be sent an improved forecast of the wind to be expected along the route.

(iv) Route and Traffic Information. On the uplink it would be possible to send data to the aircraft on route changes in airspace in which area navigation were permitted or if the route could be changed after take-off in conventional airspace. Also schemes have been proposed in which data on the surrounding aircraft could be sent to enable a display of the immediate traffic pattern to be shown in the cockpit.

6.3 Airborne Collision Avoidance System.

The Airborne Collision Avoidance System (ACAS) (Ref.8) is at present undergoing the process of approval by ICAO and is to be introduced in the USA. It is based on the use of Mode-S transponders and will give protection to an ACAS equipped aircraft even if the conflicting aircraft is only fitted with a normal Mode-C transponder. The search for a potential conflict is based on rules which are defined in terms of time-to-closest-approach (20 or 30 seconds, depending on situation) and also proximity regardless of closing rate. An alarm is given to the pilot together with an advisory manouvre which will increase vertical separation with the conflicting plane. The principle of operation is that the pilot should obey the advisory immediately since there is not time for any other advice to be sought. The intention is that it should normally function operation in all phases of flight. It is not an equipment which is yet mandatory for flight even in the US and it uses the same transponder as for the data link and the SSR surveillance.

An attractive development of ACAS would be to include a facility for monitoring on the ground the targets which are known to the ACAS equipment and also the values of the closing rate and the range. This could give confidence to the ground system that the ACAS is functioning correctly and hence that it could be used in the ATC process. A further development could be the nomination by the ground system to the ACAS of aircraft which may be coming close and which may give rise to a conflict. These ideas may enable the ACAS to operate within the ATC process where it at present acts wholly autonomously.

6.4 Equipment Reliability.

The technical advances described above could be used to change the method of control. However these all raise the problem of operational responsibility, and reliability. For instance, if traffic were to be crossed at the same level with smaller separations than at present, the controller would not be able to deal unassisted with emergencies at the closing speeds which are involved. Therefore it must be a priority to determine how the reliability of the new method could be established and safeguarded.

The redundancy in a future aircraft navigation/Mode-S data link system can be analysed in a simple way by tracing its equipment dependence, which is shown in Table 1.

The overwhelming conclusion from this summary is that all this new information is almost entirely dependant on the Mode-S transponder which is not specified as a mandatory or flight critical system in present regulations. Under present regulations even ACAS is only an advisory system and all that is required is that there should be the normal provision of a second transponder which can be switched in if the pilot is informed by ATC that the first is no longer functioning. The transponder specification has a MTBF figure laid down. The future development of Mode-S data link in more critical ATC applications may hinge on the reliability of the transponder installation being sufficient.

Once the reliability of the methods of measurement have been established then the emphasis falls on the reliability of the ground processors which will advise and assist the controller. This remains a difficult problem and not just for ATC. There is already much attention being paid to its solution for many safety critical applications, for instance in the nuclear power and defence industries.

7 CONTROL METHOD.

The principal objective of studies of the future development of air traffic management has been the desire to increase the scope for controlling traffic safely, with the same or less controller workload but in a more economical way for the end user.

7.1 The Functional Changes.

The introduction of an ATC air-ground data link together with aircraft which are fitted with advanced avionics would have an impact on two functions in the ATC process. These are firstly the prediction of the future aircraft position along a profile and secondly on the monitoring of its progress. These are both consequences of the data which may be sent up and down the link and which could become available to the controller through the data link and his computer assistance. Instead of just the radar PPI display, the mode-C height and the flight plan he could have, in principle, any of the data which is available in the aircraft avionics. That which has been listed above looks to be the most useful but it is only a selection made according to our current view of usefulness.

7.1.1 Prediction. - Instead of a method of control whereby the controller gives limited clearances for the foreseeable time ahead, he will have sufficient computing capacity and information to predict further ahead. The limit will be the knowledge of the aircraft performance, both intrinsic and demanded, and of the met conditions. So far as the aircraft is concerned, the aircraft type could be modelled on the ground and work is underway to find out how accurately this could be done within the expected computing resources. As an alternative, the FMS aircraft performance model in the aircraft itself could, in principle, be used, accessed via the data link.

The major source of uncertainty in aircraft position is the forecast of the wind which will be experienced. For example, over the area covering Europe, the North Atlantic and North America the 24 hours root mean square wind error at FL390 is 14 knots (Ref.9). If real time wind measurements were to be sent to the ground then an improved forecast of the wind to be encountered could be made. At the basic level this would be simply the measurements made by a previous aircraft on the route. This would be better in stable conditions than the present forecasts output from the Numerical Weather Prediction models by weather centres. Additional reliability in unstable conditions could be added by passing the measurements through a different form of prediction model which would produce a much more frequent output with higher accuracy which might reduce the RMS error to about half that found today. The question of exactly how valuable this would be and how much it would be worth is the subject of research at present.

7.1.2 Monitoring. - Although in the UK the controller does all his monitoring of the progress of the aircraft in his sector visually from the PPI, in other European countries there are short term conflict detection programs which aid the controller. They monitor the situation looking perhaps 2 minutes ahead and they look for any likely infringement of separation.

This could be developed and expanded in the future when more information could be available for the monitoring process. Currently there is rather a high false alarm rate but this is tolerated. With better tracking, particularly in turns, and with improved wind information the reliability of the process would be increased.

Also, if the profile were defined more precisely, the monitor could give closer attention to the aircraft progress than could the controller, and the monitoring could be expanded into an area not covered at the moment, that is into monitoring the aircraft system state. If information on the demands entered by the crew into the FMS and the mode of the FMS could be periodically checked on the ground, it would make a large contribution to the concern about wrong key inputs. For example, the monitoring of dual track airways would be eased. It could also influence the debate about the form of acknowledgement which a controller needs to confirm that his clearance has been obeyed.

It may be that the direction of computer assistance for the controller is on 'background' tasks such as the monitoring of the progress of aircraft and not on 'foreground' tasks such as tactical control.

7.2 Changes To The Method Of ATC.

7.2.1 The Acceptability Of Computer Assistance. - The practice of air traffic control is a complex interaction between the controller and the engineering tools at his disposal. Today his decisions are made on the basis of

a) a flight plan,
b) a synthetic radar display and
c) the mode-C height.

The integrity of the barometric altimeter, the encoder, the transponder, the radar processor and the display mean that they are trusted almost completely. Even if at first synthetic radar was greeted with scepticism, experience has convinced all. Originally it was felt by some that a primary radar display brought the controller 'closer' to the aircraft than secondary and so they were doubtful. Now all controllers are dependant on secondary radar and indeed would find it difficult to cope with primary unlabelled blips, especially in peak traffic conditions. A process of enhancing the capability of a controller has been going on in the last 15 years which has at the same time made him more dependant on the technical assistance. For instance, he has given over the decision about what is a real radar plot to the radar processing computer. It is however within an acceptable reliability level and so there is no worry. Also, as a radar operator he might be able to do better than the plot extractor, but that is not his main job. He is there as a controller who has to make decisions on the safety of aircraft and if he can entrust the job of information provision to a computer then he has arranged his task more efficiently. It is this process of arranging the technology to assist the controllers to do their primary task mode effectively which must be continued in future.

If the reliability level is achieved then the new technology which is available to monitor progress yields improved methods of management of air traffic. These methods may be combined to complement one another.

7.2.2 An Example Of ATC. - Consider as an example, how this technology could be involved in the task of crossing traffic at the same flight level.

a) Ground Based ATC Radars. This is the current method of surveillance using SSR which requires a transponder onboard the aircraft. Aircraft position would be measured and the velocity derived from tracking and the barometric height reported in the SSR replies. The SSR tracking would be improved by the use of air derived information such as roll angle and height rate.

b) Monitoring of On-Board Navigation Systems. Air derived position measurements would be monitored on the the ground using the ATC data link. The navigation system could be,for instance, either DME-DME/INS or a satellite system such as GPS Navstar, both of which are highly accurate.

c) Aircraft Autopilot/FMS. This would be a 4-D flight management system which would permit a specified vertical profile and route to be followed accurately and would be able to use wind data for the route up-linked from the ground. It would be able to incorporate time or height gates into the profile and plan the trajectory through them.

d) The On-board Collision Avoidance System (CAS). Any other aircraft which are crossing at the same level which may come within range would be monitored by the CAS.

e) Monitoring of the FMS Intention. The intentions which would have been inserted into an aircraft FMS would be monitored on the ground via the data link. For instance, in the example being considered of crossing traffic at the same level, the time constraint which would have been inserted in to the FMS would be checked. This would relieve the anxiety about single catastrophic errors caused by data entry and about misunderstandings.

The monitoring would not be 'by eye' but by both ATC computers and the airborne computers each of which could check on the other. This monitoring system would be built on the monitoring which would have already been introduced into ATC as part of earlier stages of computer assistance; for instance in a metering/sequencing system for arrival traffic. The controller therefore would be faced with adding the new monitoring functions which would arise from the use of a data link which will enable him to sequence traffic through junctions with more demanding criteria and safeguards.

The met data used in predicting the trajectory would be the same in the air and on the ground and would have been derived from measurements made by previous aircraft.

There will be a mix of aircraft capabilities in controlled airspace for a long time and it will be a matter of international debate how the mix of aircraft should be accomodated. It may be that the controller can assist the poorly equipped aircraft to operate in the new ATC environment using his own computer assistance. It may be that a manual form of ATC will have to be retained with preference given to modern aircraft for the best flight levels and peak times at busy airports. The conclusion may depend on the classes of avionic fit which are defined and the numbers of aircraft in each class. This mode of operation could also be the reversionary mode for equipment failure.

This method of ATC has been outlined rather simplisticly without dwelling on the complexities which would arise in defining and implementing such a system. This has been done to draw out the fact that there will exist a range of technology which could permit a radical but safe change to the methods of ATC for the same level of controller workload. A more precise planning capability would be given to the controller and with it a tighter automatic monitoring task which would be designed to provide an additional level of assurance to him.

8 CONCLUSIONS.

There is a range of new technology which may be applied to the task of controlling air traffic at junctions. This technology is both in the aircraft and on the ground and it is bound together by a data link.

The advantage to be gained from the new technology is not always a direct increase in capacity but it may be an increase in aircraft efficiency and/or a reduction in controller workload.

The benefits and consequences to air traffic control from the application of new technology may be summarised as follows.

i. There would be considerable benefit from being able to utilise fully the economic flight levels at junctions. This is particularly true where the complexity of the airspace means that aircraft are left in the uneconomic levels for a long time.

ii. The ability to cross traffic at the same flight level without an addition to controller workload would be a major addition to the armoury of the airspace designer.

iii. Short term planning systems such as are in service today could already benefit from the following consequences of the use of a data link,

- = improved wind forecasts,
- = ground monitoring of avionics,
- = ground monitoring of pilot inputs,
- = more accurate monitoring of aircraft progress.

iv. A higher level of safety against "blunder" errors would come about through monitoring of aircraft intention.

v. There is a new field of integrated ground/air prediction and monitoring which would be opened up by the use of 4-D FMS avionics, an ATC data link and a development of ACAS.

vi. Application to strategic planning systems could greatly increase their reliability and provide the springboard for development of more advanced control techniques based on the full use of the capabilities of aircraft equipped with 4-D FMS.

vii. The safety implications of the use of the mode-S transponders for several functions will need careful assessment.

viii. The problem of how to ensure the reliability of the ground processing computers and their software in critical tasks remains to be solved.

ix. In an integrated air traffic management system which seeks to utilise the control capabilities of aircraft flight management systems, there will need to be a compromise between the economics of flying high and the need for sufficient speed variation to be able to manage the air traffic.

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Measurement	Data Source
HEIGHT	Mode-C SSR
HEADING	Data Link
SPEED	Data Link SSR Tracking
POSITION	SSR Data Link
OTHER AIRCRAFT PARAMETERS	Data Link
ENVIRONMENT (wind)	Data Link
COLLISION AVOIDANCE	ACAS

TABLE 1. Dependence on the Mode-S Transponder for SSR, Data Link and ACAS

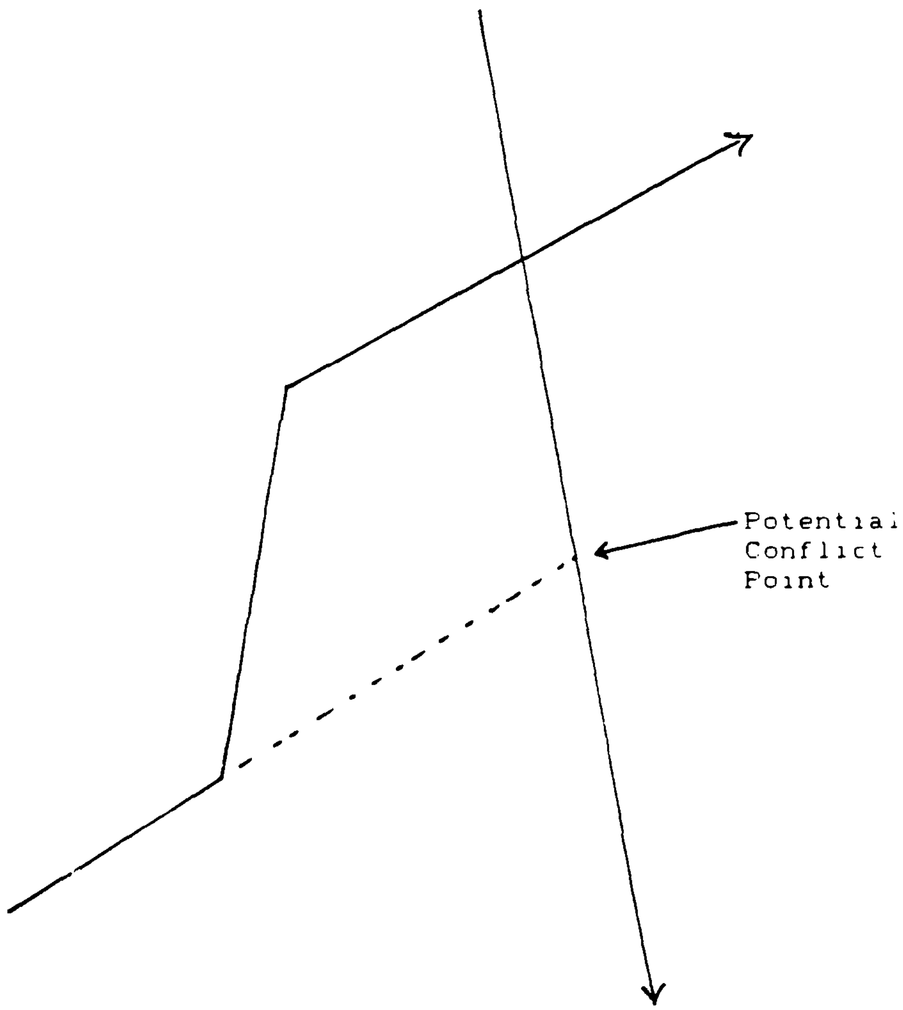

Figure 1. Separation by Vectoring

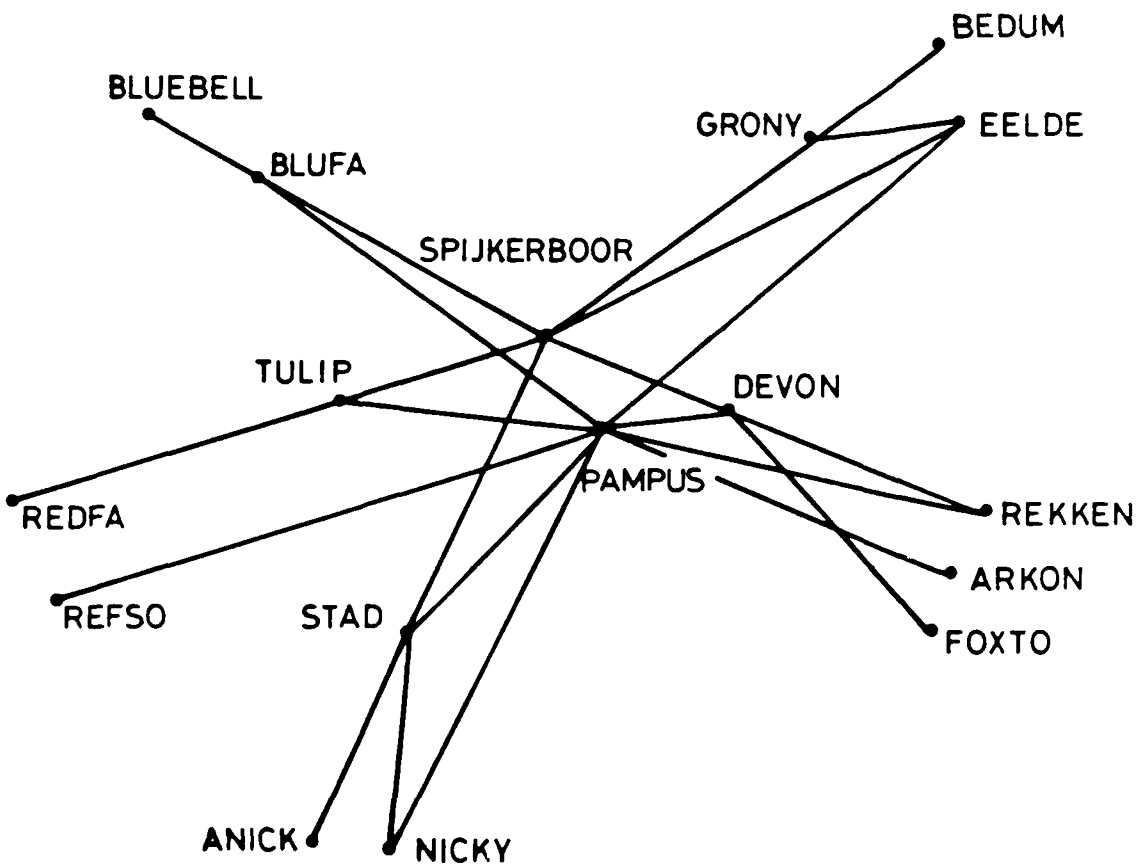

FIG. 2. THE SPY-PAM INTERSECTION FOR OVERFLYING TRAFFIC

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